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SOME SPECTRAL CHARACTERISTICS OF CEPHEID VARIABLES

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In a recent investigation of the absolute magnitudes of 500 stars[1] we have shown that in a large number of cases the intensity of the hydrogen lines is abnormally great in relation to the spectral type as derived from the more general characteristics of the spectrum. The effect is most striking in the case of giant M-type stars such as α Orionis, but it is marked for many K and G-type spectra as well. The suggestion was made that abnormal intensity of the hydrogen lines is a general characteristic of the giant stars of at least some of the spectral types. A discussion of this question with reference to certain of the variable stars of the δ Cephei type is the object of this communication.

It has been shown by the investigations of Hertzsprung[2] and others that the Cepheid variables are stars of very high intrinsic luminosity, with an average absolute magnitude, as derived from parallactic motion, more than seven magnitudes brighter than the sun. Directly measured parallaxes of five stars yield a value of about five magnitudes. Whichever result is accepted it is evident that these stars are exceedingly luminous and form most interesting material for a study of the question of the intensity of the hydrogen lines.

The spectrum of the Cepheid variables has been studied by many observers, and it is quite impossible to make adequate reference to their results in this place. In general, however, most of the work of Albrecht[3], Duncan[4], Shapley[5], and many others has dealt with variations in the character of the spectrum at maximum and minimum of light. For the purpose we have in mind a direct comparison is instituted between the spectra of the several variables and that of the sun, which is selected as a typical star of type G_0. Photographs of the spectra, all of which were made with a slit spectrograph, taken at maximum and minimum of light are also compared directly with one another. Furthermore typical stars having spectra of types F_0, F_5, and G_5 have been

selected from among those classified by the Harvard observers, and these spectra have been used for comparison purposes as well as that of the sun. The spectra have been compared by the aid of a Hartmann spectro-comparator.

A summary of the results is given in brief form in the accompanying table. It became clear from the very first comparisons that the hydrogen lines are abnormal in the Cepheid spectra, being in some cases several times as strong as in the sun, although in other respects the spectra do not differ greatly. We have accordingly adopted the plan used in previous investigations of making two determinations of spectral type. The first is based upon the hydrogen lines alone; the second upon the more general features of the spectra, in particular, the intensities of the arc lines of the various elements, and other characteristics which seem to be primarily a function of general spectral type.

	MAXIMUM OF LIGHT		MINIMUM	
	Hydrogen	General spectrum	Hydrogen	General spectrum
TU Cassiopeiae	F_0	F_9	F_8	F_9
SU Cassiopeiae	F_3	F_7	F_6	F_8
SZ Tauri	F_0	F_8	F_6	F_8
T Monocerotis	F_0	G_0	F_7	G_1
RT Aurigae	F_0	F_7	F_8	G_0
W Geminorum	A_9	G_0	F_6	G_0
ζ Geminorum	F_2	F_9	F_3	G_0
η Aquilae	F_3 (near max)	F_9	F_8	G_1
δ Cephei	F_2 (near max)	F_9	F_9	G_0
Mean	F_1	F_9	F_7	G_0

Three conclusions may be drawn from these results: First, that the hydrogen lines are abnormally strong in all of these stars, the difference translated into spectral type amounting to eight divisions of the Harvard scale at maximum of light: Second, that at minimum this difference is reduced, amounting in the average to but three divisions: Third, that there is little or no difference in the general spectrum at maximum and minimum so far as the criteria here used are concerned. Certain differences in other respects will be referred to presently. The general conclusion may therefore be drawn that the variation in spectral type among the Cepheid variables is mainly a variation in the intensity of the hydrogen lines.

The determination of spectral type of several Cepheid variables by Shapley[5] and of δ Cephei by Adams and Shapley[6], were based wholly on the hydrogen lines, the anomalous behavior of these lines in many stars not being fully recognized when the earlier work was done. A comparison of the present spectral determinations from the hydrogen lines with those of Shapley for seven stars common to the two lists shows a close degree of accordance in the amount of variation at maximum and minimum of light. The values are seven

and eight spectral divisions in the two cases respectively. There is, however, a small systematic difference in spectral type at both maximum and minimum, the types given here being on the average slightly earlier.

It is clear from the very special character of the variations in the spectra of the Cepheid variables that it is doubtful if they can be regarded as furnishing direct evidence as to the order of evolution of stars in general. In the normal succession of spectral types changes in intensity of the hydrogen lines are accompanied by numerous important changes in many features of the spectrum which appear to remain essentially unaltered in the spectra of the Cepheids.

Reference has been made to certain differences in the spectra of these stars at maximum and minimum of light other than those in the hydrogen lines. The most important of these are: (1) a shift of the maximum of the continuous spectrum toward shorter wave-lengths at maximum of light, a result found by Albrecht[5]: (2) a general slight widening of the spectral lines at minimum: (3) an increase in the intensity of the so-called 'enhanced' lines at maximum. The last two characteristics were noted in the investigation of the spectrum of δ Cephei by Adams and Shapley[6]. The change in the enhanced lines is probably most significant in its bearing on the variation of absolute magnitude. The three lines principally used for the determination of absolute magnitudes of stars of this type of spectrum are all strongly enhanced and it seems probable, as we have suggested previously, that enhanced lines as a class vary with luminosity. Accordingly we have compared the intensities of some of the more prominent enhanced lines in the spectra of these variables with their intensities in the solar spectrum, and also on the photographs taken at maximum and minimum of light. In all cases these lines are much more intense in the stellar spectra, and to a less degree more intense at maximum than at minimum of light. Among the lines are the following:

4077 Sr	4233 Fe	4290 Ti	4385 Fe	4584 Fe
4215 Sr	4246 Y	4376 —	4534 Ti	

Of these λ 4077 shows the largest difference, being fully five times as strong in some of the stellar spectra as in the sun. With the aid of the reduction curves for absolute magnitude, the difference in the intensities of the three lines λ 4077, 4215 and 4290 at maximum and minimum of light may be converted into differences of magnitude. They give for the average of the nine stars the values 0.8, 1.3 and 0.6, respectively, or a mean of 0.9. This is in very fair agreement with the average variation in apparent magnitude of 0.7 for the same stars.

Two other features of the spectra of this class of variables may be referred to briefly. The first is the marked difference in the relative intensities of the hydrogen lines when compared with the solar spectrum. In the sun the line Hβ is considerably more intense than Hγ, but in all of the Cepheid spectra the reverse is the case, Hγ being much stronger than Hβ. At minimum of

light this effect is slightly less marked than at maximum. It seems probable that we are dealing here with a shift in the maximum of intensity of the line spectrum of hydrogen similar to that which occurs in the continuous spectrum. It has been shown in the laboratory that in the case of lines belonging to the same series increase of temperature increases the intensity of the more refrangible lines, the maximum moving toward shorter wave-lengths. In such high luminosity stars as the Cepheid variables such a difference as compared with the sun is highly probable.

It is of interest to note in connection with a study of the spectra of these variable stars that the spectra of certain stars which, with the exception of ρ Cassiopeiae, are not known to show light variation have very similar characteristics both as regards the intensity of the hydrogen and the enhanced lines. The most promient cases of this kind are the following:

	R. A.	DEC.	GAL. LONG.	GAL. LAT.
δ Canis Majoris	$7^h\ 4^m$	$-26°\ 14'$	204°	$-8°$
ξ Puppis	7 45	$-24\ 37$	211	0
γ Cygni	20 19	$+39\ 56$	45	$+2$
Boss 5931	22 56	$+56\ 25$	75	-5
ρ Cassiopeiae	23 49	$+56\ 57$	83	-5

The star δ Canis Majoris has been found at the Lick Observatory to show a small variation in radial velocity. Some of these stars have spectra nearly identical with that of the Cepheid variables, and it is an interesting fact that all of them are situated very near the galactic plane and thus share in the peculiar distribution of the latter.

[1] Adams, W. S., and Joy, A. H., *Mt. Wilson Contr.* No. 142; *Astroph. J., Chicago*, **46**, 1917, (313–339).

[2] Hertzsprung, E., *Astr. Nachr., Kiel*, **196**, 1913, (201–208).

[3] Albrecht, S., *Lick Obs. Bull., Berkeley*, No. 118.

[4] Duncan, J. C., *Ibid.*, No. 151.

[5] Shapley, H., these PROCEEDINGS, **2**, 1916, (208–209); also *Mt. Wilson Contr.* No. 124.

[6] Adams, W. S., and Shapley, H., these PROCEEDINGS, **2**, 1916, (135–142).

TYPES OF ACHROMATIC FRINGES

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The difficulty of obtaining fringes of the strictly achromatic type (i.e., two strong fringes with a black line between and the remaining fringes green-